

Modelling of Impact on a Fuel Tank Using Smoothed Particle Hydrodynamics

R. Vignjevic^a, T. De Vuyst^a, J. Campbell^a, N. Bourne^b

School of Engineering, Cranfield University, Bedfordshire, MK43 0AL, UK.^a
RMCS, Cranfield University, Shrivenham, Swindon, SN6 8LA, UK.^b

Abstract

This paper describes a modelling approach for the simulation of hypervelocity impact on fuel tanks using the Smoothed Particle Hydrodynamics (SPH) method. To determine a suitable particle density, three two-dimensional axi-symmetric models were analysed. Then three-dimensional simulations with cylindrical and cubic penetrators were performed. For each analysis the transient pressure values at locations corresponding to experimental transducer locations were recorded. The pressure time histories are shown for the axi-symmetric and 3D models. The simulation results are compared with the experimental results. The purpose of the research was to demonstrate the capability and potential of SPH for simulating this type of problem.

Introduction

Gingold and Monaghan [1] and Lucy [2] independently developed the Smoothed Particle Hydrodynamics (SPH) method in 1977 for the simulation of astrophysics problems. The strength and attraction of SPH is that the calculation of derivatives does not require a structured computational mesh. Over the ensuing ten years SPH continued to be developed and applied for analysis of astrophysics problems, principally by Monaghan and his co-workers [3,4,5]. The state of SPH development at this time is covered in two review papers, one by Benz [6] and the other by Monaghan [7].

In 1990 Libersky and Petchek [8] extended SPH to work with the full stress tensor, developing a 2D axi-symmetric plane strain formulation. Work on developing SPH with strength of materials was continued with the extension to a 3D-method [9]. This development enabled analysis of problems in continuum mechanics characterized by extremely large deformations, wave propagation and moving interfaces between solids and liquids. These are all characteristics of the hydraulic ram problem.

Hydraulic ram is a phenomenon that can occur during ballistic impact on liquid filled containers, such as fuel tanks. The projectile impact on the tank wall results in a pressure wave that propagates through the fluid within the tank. This pressure wave stresses the walls of the tank, significantly increasing the risk of catastrophic failure at the projectile entry or exit points.

Numerical modelling of hydraulic ram involves a number of physical phenomena including high velocity impact and penetration, large deformation and material failure, fluid structure interaction and shock physics including change of phase. Traditionally, high velocity impact problems of this type have been modelled using either Lagrangian or Eulerian formulations or using hybrid approaches such as Coupled Euler-Lagrange (CEL) or Arbitrary Lagrangian Eulerian (ALE).

The work presented in this paper involved numerical modelling of the phenomenon of hydrodynamic ram using SPH. Two types of analyses were performed that can be categorized as follows:

- Axi-symmetric
- 3D with cylindrical and cubic penetrator

The axi-symmetric analyses allowed for a fast sensitivity study of discretisation density. In the axi-symmetric analyses the penetrator was modelled as a cylinder of equivalent mass to the cube used in experiments. The 3D analysis with a cubic penetrator represents the most accurate model of the problem geometry described below. The 3D models had lower resolution compared to axi-symmetric model.

For each analysis the transient pressure values at the transducer points are reported. The pressure time histories are shown for the response time between 0 and 100 ms. The simulation pressure time histories were compared with the experimental data measured at the same locations. It is important to point out that in the experiment pressure transducer number 1 was hit by the projectile and displaced from its initial location. Therefore the pressure history for this sensor should be interpreted with caution.

The cavitation process of the water was treated in a very simple way. The cavity was allowed to form by the projectile penetration and the associated flow. Regardless of the simplicity of this approach cavity shapes agreed well with published cavity shapes [10, 11].

Problem Description

A schematic representation of the fuel tank cross section is shown in Figure 1. The dimensions of the fuel tank were 400 X 400 X 100 mm with the face sheet thickness of 1.2 mm. The projectiles were made from steel. Impact velocity was 1850 m/s. The tank was filled with water. Pressure transducers were located on the tank mid-plane (see Figure 1).

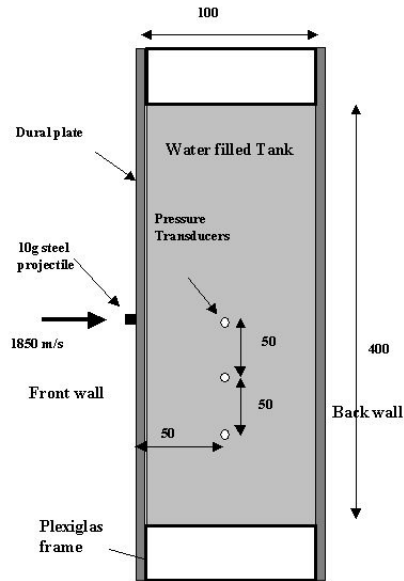


Figure 1. Schematic representation of the fuel tank and the projectile. Dimensions are in millimetres.

Modelling

The strength model used for fuel tank aluminium walls and the steel projectile was a Johnson Cook material model with failure. The hydrodynamic response for all materials was modelled with a Mie–Gruneisen equation of state.

Axi-symmetric model

The first issue considered was discretisation density sensitivity. To determine the sensitivity of the problem to particle density, and to determine an adequate discretisation density, three different axi-symmetric models were analysed. Axi-symmetric models were used to minimize the run time. The only parameter changed between the three analyses was particle density. The models considered had 2, 3, and 5 particles through the thickness of the aluminium plates.

Comparison of results for the models with three particles through the plate thickness and the models with five particles through the plate thickness showed that there is no significant difference in the response. Therefore, in the 3D analysis models with three particles through the plate thickness were used.



Figure 2. Axi-symmetric model of the fuel tank (35823 particles)

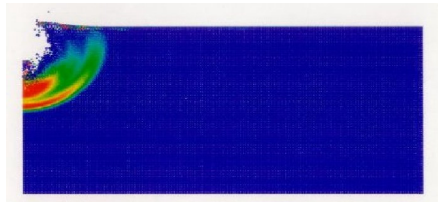


Figure 3. Pressure distribution for axi-symmetric model at time 20 ms

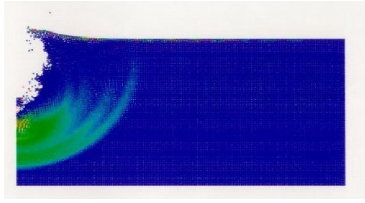


Figure 4. Pressure distribution for axi-symmetric model at time 20 μ s



Figure 5. Pressure distribution for axi-symmetric model at time 100 μ s.

Pressure distributions and plate deformation for Model 2 (shown in Figure 2), with three particles through the plate thickness, at times 20, 60 and 100 μ s are shown in Figures 3 to 5. Pressure and shock wave velocity in the axi-symmetric model compared well with the experimental values (12% difference). The pressure transducer time histories for the model are shown in Figure 6. The projectile did not fragment, only a few particles separated as a consequence of numerical fracture. A spall model based on hydrostatic tension was used for the projectile and the aluminium plates. The cavity observed in this model has a shape similar to the cavity shape reported in [10, 11].

In the pressure time history results shown, transducer 1 is the transducer in the centre of the tank, in-line with the projectile. Transducer 2 is 50 mm from transducer 1. The remaining transducer is number 3. The numerical curves labelled 1,2 and 3 are taken from positions corresponding to the locations of transducers 1,2 and 3 respectively.

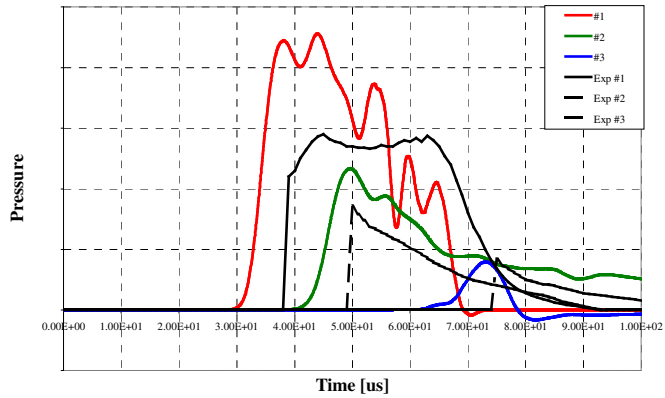


Figure 6. Pressure transducer time histories for axis-symmetric model.

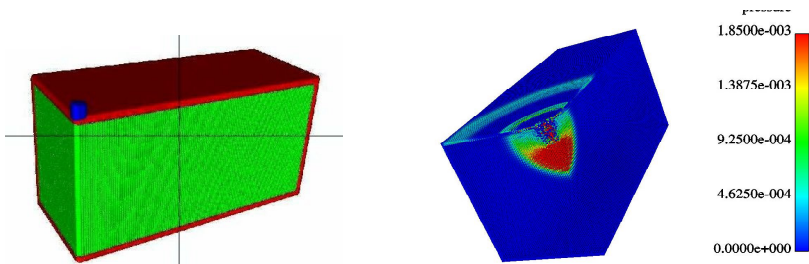


Figure 7. 3D model of the fuel the tank with the cylindrical projectile (568000 particles)

Figure 8. Pressure distribution for the 3D model with the cylindrical projectile at time 20 μ s

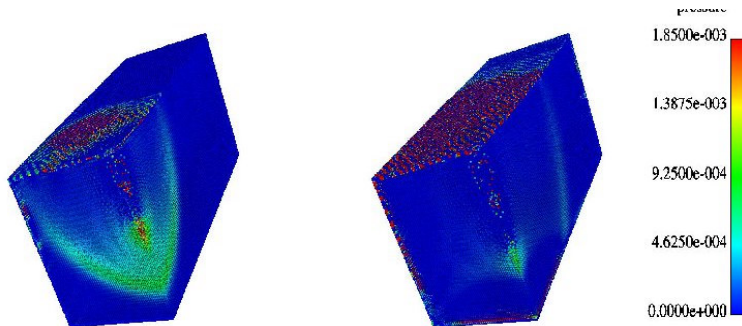


Figure 9. Pressure distribution for the 3D model with the cylindrical projectile at time 60 μ s

Figure 10. Pressure distribution for the 3D model with the cylindrical projectile at time 100 μ s

3D Models

Two 3D models with three particles through the plate thickness were generated. The projectile has a cylindrical shape in model 1 and cubical shape in model 2. The initial geometry of model 1 is shown in Figure 7.

Pressure distributions and plate deformation for the model with the cylindrical projectile at times 20, 60 and 100 μs are shown in Figures 8 to 10. The difference between the model 1 and model 2 global result plots is not significant; therefore only global pressure plots for model 1 are shown. Pressure transducer time histories for the 3D models 1 and 2 are shown in Figures 11 and 12 respectively. Pressure and shock wave velocity in the 3D and axi-symmetric models are similar.

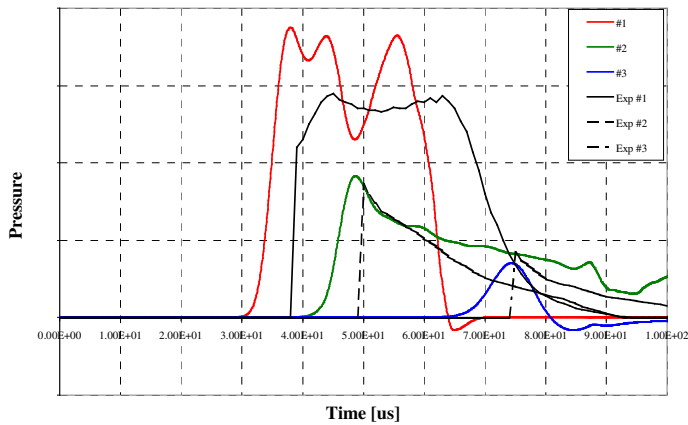


Figure 11. Pressure transducer results for 3D model with cubical projectile

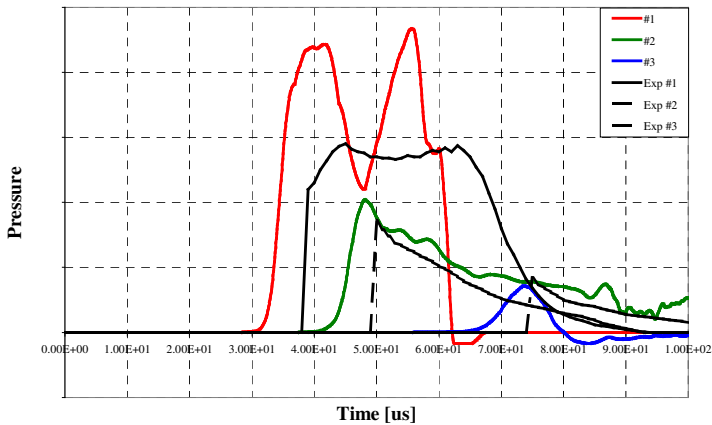


Figure 12. Pressure transducer results for 3D model with cylindrical projectile

In the 3D models the projectiles behaved similar to the projectiles in the axis-symmetric models and did not fragment. Few particles separated from the projectiles as a consequence of numerical fracture. The spall model based on hydrostatic tension was used for the projectile and the aluminium plates. The cavity in this model has a shape similar to the cavity shape of the axis-symmetric model.

Conclusions

The limited work presented in the paper leads to the following conclusions regarding SPH simulation of projectile impact on fuel tanks with thin walls. The simple models used were capable of capturing the relevant physics characterizing the impact. Consequently the SPH method, even with its known limitations, represents a viable tool for analysing hydraulic ram impacts.

References

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